Renewable and Sustainable Energy Reviews 16 (2012) 4661–4666

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Identification of stakeholders for sustainable renewable energy applications in Cameroon

E.M. Nfah [a,b,*], J.M. Ngundam [c]

[a] Laboratoire d'Automatique et d'Informatique Appliquée, I.U.T. Fotso Victor, P.O. Box 134, Bandjoun, University of Dschang, Cameroon
[b] Department of Electrical and Power Engineering, Higher Technical Teachers' Training College, P.O. Box 39, Bambili, University of Bamenda, Cameroon
[c] Automation and Control Laboratory, School of Engineering, P.O. Box 8390, University of Yaoundé I, Cameroon

ARTICLE INFO

Article history:
Received 16 September 2011
Received in revised form
8 May 2012
Accepted 8 May 2012
Available online 27 June 2012

Keywords:
Local management committees
Microfinance institutions
Non-governmental organisation
Renewable energy enterprises
Universities

ABSTRACT

This paper examined the initiation, funding, realisation and the current state of some renewable energy applications in the West Region of Cameroon. The findings from the study conducted showed that all of the renewable energy applications were initiated by indigenes living outside the beneficiary communities. The lack of fee-for-service tariffs was partly responsible for the failure of a wind electric installation for potable water pumping. Conflicts in a local management committee resulted in the inoperative state of a pico-hydro installation, while the lack of finances accounted for the failure of a PV system of rural Health Centre. Although, some successful results were noted in the activities of African Center for Renewable and Sustainable Technologies (ACREST) involving foreign technical expertise in small scale renewable energy applications, ACREST had difficulties with the implementation of 100 kW micro hydro project. The stakeholders identified for successful renewable energy applications in Cameroon included local management committees, microfinance institutions, Non-Governmental Organisations (NGOs), Renewable Energy Enterprises (REEs) and universities. Local management committees must be in charge of the supervision, operation and maintenance of installed systems as well as revenue collection based on fee-for-service tariffs. Microfinance institutions should grant loans for the acquisition of financially and economically viable off-grid renewable energy systems to communities with monthly installments based on established monthly energy expenditures. NGOs are expected to provide technical assistance for the conception of community projects, the procurement of funding from cooperation partners and for the realisation of projects. REEs should have competence for sizing, installation and post-installation maintenance of renewable energy equipment. Universities must train the technicians and engineers that will be used by NGOs and REEs. This important role has been recognised by the government of Cameroon through the creation of the first Department of Renewable Energy at the University of Maroua in 2008.

Contents

1. Introduction

Cameroon is a Central African country with a surface area of 475,440 km^2 and a population estimated at 15.5 million inhabitants in 2001. The country possesses the second hydroelectric potential (294 TWh) in Africa after the Democratic Republic of Congo (about 1000 TWh). In 2002, electricity generation from

* Corresponding author at: Department of Electrical and Power Engineering, Higher Technical Teacher's Training College, P.O. Box 39, Bambili, University of Bamenda, Cameroon. Tel.: +237 9688 2160; fax: +237 3301 4601.
E-mail address: emnfah@yahoo.com (E.M. Nfah).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.05.019

hydro resources accounted for 85% and thermal electricity 15% [1–3]. The average rate of electricity access for Cameroonian households in urban and rural areas has been estimated from surveys of household living standards of 1996 and 2001 as 46.1%. This rate comprises 25.9% households connected through utility metres and 20.1% households linked to the utility meters of neighbours [1,2]. The electrification rate in rural areas which are home to 62%–70% of the population is very low and estimated to be in the range of 4%–6% [1,2].

The low rate of utility connections in grid-connected areas can be attributed to high costs of low voltage connections presented in Ref. [3] and low energy consumptions that have been determined in the range of 5.8–25 kWh/month [4]. According to the electricity tariff structure presented in Ref. [4] for households with a power subscription of 2.2 kW, the monthly electricity bills are in the range of 1.46–2.92 € (1 € = 1.3334 US$). Thus, the cost of low voltage grid connexions for distances up to 100 m amount to energy bills for about seven years for high energy households and fourteen years for low energy households. This explains why, most poor households in urban and rural areas are often linked to the utility meters of households that can pay for a grid connection.

The low rate of rural electrification in Cameroon is mainly linked to high costs of grid extension [1,2]. The large losses associated with the transmission and distribution networks required for the supply of electricity, to remote villages characterised by few and sparsely distributed households with low aggregate energy demand is uneconomical for the power utility. Thus grid extension for rural electrification is often executed by the Rural Electrification Agency based on state budgetary allocations. The single wire earth return (SWER) grid extension method practiced in Cameroon is shown in Fig. 1. The cost of laying a 30-kV MV-line over 1.5 km, the installation of a 17.32 kV/220 V 25 kVA single phase autotransformer and a 220 V distribution network for village electrification in the West Region was evaluated by AES-SONEL in 2004 at 20,543 € including taxes of 18.7%. The cost of laying the 30-kV MV-line accounted for 26.2%, the installation of the autotransformer 30.2% and the low voltage network 43.6%. Thus the cost of laying a 30-kV MV-line can be estimated at 3589 €/km. It is thus obvious that most remotely located and inaccessible villages will remain non-electrified unless alternate solutions are evaluated.

The analysis of the monthly energy consumptions data of 83 selected Indian villages used in Ref. [5] for the evaluation of the optimal mix of renewable technologies shows that 72 (86.7%) villages had daily energy consumptions less than 60 kWh/d. Load profiles with energy and night peak power demands in the ranges 30–50 kWh/d and 3–5 kW respectively have also been considered in the evaluation of off-grid power options for remote villages in Brazil, India, Lao PDR, and Senegal [6–9]. Furthermore the operational data of 20 kW woody biomass-based power plants for 1998–1999 in two villages in southern India, showed that the power plants operated for 3–4.5 h/d and 327–349 d/year, generated 16–38 kWh/d for village energy needs for lighting, potable water pumping and grain milling [10]. In Senegal village scale solar powered mini-grids have been designed with energy demands of 60 and 70.7 kWh/d and implemented in the villages of Diaoule and Ndiebel with populations of about 2000 inhabitant situated at about 15 km from the nearest grid line [11–12].

Fig. 1. SWER village electrification in Cameroon.

A typical village load profile with an energy demand of 72.3 kWh/d used in Ref. [1] showed that optimal off-grid power options were found at breakeven grid distances in the range 12.9–15.2 km, for grid extension and annual maintenance costs of 5000 €/km and 125 €/km respectively [1,2]. Recently, optimal solar hybrid systems have been determined for an energy demand of 7.08 kWh/d at a breakeven grid distances of 5.9 km using a PV module cost of 7.5 €/Wp and remote fuel diesel price of 1.12 €/l. In spite of these research findings, the high investment involved in small and large scale village power options is a major obstacle for implementation since appropriate funding mechanisms are yet to be developed.

Consequently, households in non-electrified villages in Cameroon will continue to use fuelwood for cooking, kerosene for lighting, dry cell batteries for portable radio sets, automotive batteries for lighting, listening to the radio and/or watching television. In some cases small petrol generators are used by households usually at night during festive periods or on business days to operate musical sets. Solar home systems or automotive batteries may be used to supply the low energy needs of households for lighting and entertainment (operation of radio cassettes and black and white television sets) [13–17]. In addition to household demands, electrical energy is required at health centres, water pumping facilities, education and commercial centres in a village. In most remote parts of Cameroon, health centres lack grid electricity. Consequently, the quality of health care service is limited due to inability to use laboratory equipment and refrigerators for the preservation of vaccines.

In the West Region of Cameroon, some standalone photovoltaic or wind electric systems and/or pico-hydro systems have been installed to supply the electrical needs in some villages based on different methods of project initiation and implementation. Section 2 of this paper presents the origin of existing renewable energy applications in the West Region of Cameroon. Section 3, examines the current state of renewable energy applications. Section 4 identifies the roles of stakeholders for the acquisition and sustainable use of renewable energy applications in Cameroon. Section 5 dwells on the conclusions of the paper.

2. Renewable energy applications in the West region of Cameroon

The first site of renewable energy applications in the West region, is found at the integrated health centre of Djetcha-Baleng (5° 31'N, 10° 25'E), which is about 20 km from Bafoussam (5° 29'N, 10° 24'E) in the Mifi Division. Fig. 2 shows the health centre with a PV array on its roof and a standard 220 V distribution line connected to it from a 5 kW pico-hydro power plant. The PV array, battery bank, two solar charge controllers and 300 W inverter were installed in 1992 for lighting at night and for the supply of power to a vaccine refrigerator. The pico hydro scheme

Fig. 2. Djietcha-Baleng integrated health centre.

Fig. 3. Penstock pipes, powerhouse and low voltage distribution line.

Fig. 4. Water turbine, generator and grinding machine.

located at 2 km from the health centre was realized in 2006 after the PV system became inoperative in 2005. Figs. 3 and 4 show parts of the pico-hydro scheme.

The second site for renewable energy application is found at the sub-divisional hospital of Ndoh-Djutitsa (5° 25'N, 10° 41'E) located in the Menoua Divison of the West region of Cameroon. A wind installation comprising two wind turbines each rated 1 kW, a battery bank and a 2.5 kW inverter was realized in 2006. The system was implemented to supply power to the AC-water pump of a grid-connected hospital in a bid to valorise the wind potential of the area. Fig. 5 shows the wind electric installation.

The third site for renewable energy applications is found at Bangang (5° 34'N, 10° 11'E) located in the Bamboutos Division of the West region of Cameroon. A 500 W pico hydro generator imported from Vietnam was installed in 2006 for the supply of electricity to the office and the telecommunications equipment of African Center for Renewable and Sustainable Technologies (ACREST). The 500 W pico hydro scheme is shown in Fig. 6. In the absence of a grid connexion for welding and machining activities at the centre, a 6 kW generator driven by an internal combustion (IC) engine was initially used. In order to reduce the consumption of fuel a biogas digester with a biogas production capacity of at least 3 m^3/day was realized and coupled to the IC engine.

The use of biodiesel after the start-up of the IC engine on diesel has reduced the daily consumption of diesel by 30%. Initially, animal waste for the biogas digester was sought and transported

Fig. 5. Wind electric pumping system at Ndoh Djuttitsa.

Fig. 6. 500 W pico hydro scheme at Bangang.

from poultries and piggeries situated at Mbouda, some 40 km away until locally available sun flower was accidentally tested.

3. Origin and state of renewable energy applications in the West region of Cameroon

The photovoltaic system for the integrated health centre at Djetcha Baleng was donated in 1992 by an indigene of the area living in Douala, the economic capital of Cameroon. The system operated successfully up to 2005 and the integrated health centre was lighted at night and vaccines were properly preserved. However, the electrically operated microscope could not be used due to the limited power rating of the inverter. The system became inoperative due to the failure of one of the two charge controllers that linked the photovoltaic array to the battery bank. The failure of the PV system has been reported to the authorities of the Regional delegation for Public Health, but no action towards the rehabilitation of the solar energy system has been undertaken. Following the failure of the solar energy system, patients were advised to go to Bafoussam for health services that the health centre could no longer offer.

The failure of the PV system resulted in the search for an alternative source of energy since there is no grid-extension project planned for the electrification of the health centre or the area. The community identified a small stream that could be used for pico hydro generation some 2 km from the health centre. A Non Governmental Organisation (NGO), promoters of renewable energy technology based in Bafoussam known as Action pour le Développement Equitable et Intégré et Durable (ADEID) assisted the community in the conception of a pico hydro project and also secured 70% funding from GTZ for the implementation of the project. The total cost of the 5 kW hydro scheme in 2006 was about 10,000 € [1].

The villagers provided labour for the carrying of stones and sand, for the construction of the water intake, water retention and filtration tanks, penstock and power house. GTZ provided funding for a grinding machine, a water turbine, a generator, electric poles and cables. A local management committee was created after the project was realized. The installation provided electricity to the integrated health centre during the wet season of 2006 and the health facility started conducting laboratory tests.

After some months of normal operation during the rainy season, the generator house supervisor preferred using the mechanical power from the water turbine on the grinding machine for personal gains. Thus, the electricity supply to the health centre and connected households became erratic. This situation lead to disarray in the management committee resulting in the lack of maintenance of the water intake and the pico hydro system also became inoperative under less than a year. The problems in the management committee were later resolved by ADEID and the system started working again. In spite of the possibility of having electricity supply from the solar and pico hydro systems a changeover system prohibits the simultaneous use of both sources. The expandable AC-bus configuration based on bi-direction inverters [18] can be used to integrate the existing solar and hydro generators and eventually a diesel generator using biodiesel fuel.

The wind electric water system at Ndoh-Djuttitsa was initiated by an indigene of the area studying in France. The cost of the project including the travelling and living costs of three persons was about 27, 441 €, was raised in France [19]. The equipment for the wind installation benefited from tax exoneration from the Ministry of Finance as a result of an application that was introduced by the Rector of the University of Dschang (UDs). The Rector of UDs initiated this application, because the components of the wind electric installation were shipped to Cameroon together with equipment that was donated by a French University, to the Department of Civil Engineering of IUT FOTSO Victor (IUT-FV) of UDs. Some students in the final year of undergraduate studies in the Department of Electrical Engineering of IUT-FV of UDs participated in the installation of the wind electric pumping system [19].

The system after installation in August 2006 pumped water three times per day into a tank of capacity 1 m^3. The pumped water satisfied the water needs of the hospital and the surplus water was collected by villagers who previously fetched water from running streams. During 14 months of successful operation, the incidence of water related diseases reduced significantly. The electricity bill of the hospital also reduced drastically during this period, since the electrically driven water pump was diverted to the wind electric system. The 2.5 kW inverter failed due to overloading caused by the connection of the water pump to an overhead tank of greater capacity constructed by the village development association. After the failure of the inverter, the grid electricity was again used for water pumping and the electric bills of the hospitals increased sharply since the villagers continued fetching water at the hospital. A few months later, the health authorities in charge of the payment of the electricity bills ordered the disconnection of the pump.

The wind electric system failed due to the fact that a qualified technician was not hired by the beneficiary community for post-installation operation and maintenance of the components of the wind electric installation. The project conception and realisation did not define the roles of local health authorities and the beneficiary community following the commissioning of the wind electric water pumping system. The absence of a local management committee in charge of supervision of exploitation of the wind electric installation, paved the way for the leaders of the village development association who often have residence in towns to conduct an unwise experiment on the wind installation.

The inverter is yet to be replaced by the overzealous village association, and there are no plans for its replacement at the level of the local health authorities. Possible explanations include the lack of documentation for installed components of the wind electric system and the inexistence of local expertise for the repair of the inverter which was imported. A major contributing factor to the failure of the wind electric system is the fact that UDs were only implicated at the level of the request of tax exoneration. The post-installation role of the university was not defined at the conception of the project.

The renewable energy applications of ACREST have been initiated and sponsored by an indigene of the area working at UN Habitat in Kenya. The main area of activity of ACREST is in the development of pico hydro and micro hydro schemes for electricity production. The centre started off with a large mechanical wheel connected to a 6 kW generator through a speed transmission gear system. The mechanical wheel is rotated by water obtained through a diversion channel that includes sliding gates for manual regulation of water flow. The system works well during the wet season when the water diversion receives enough water from the nearby stream.

In order to power office and telecommunications equipment on a daily basis, the centre purchased a 500 W pico hydro generator from Vietnam. The implementation phase involved the Clean Energy Consortium of the University of Dschang in the fabrication of the water diversion canals and the European expertise in the design of the water canals. Since its installation in 2006, the pico hydro system has not had any operational problems. The power output of the pico generator is rectified and connected to an office lighting system made of a network of light emitting diodes. The office computer and telecommunication equipment are connected directly to the output of the 500 W

Fig. 7. Fabrication of a 500 W pico hydro generator.

Fig. 8. Penstock works for 100 kW micro hydro plant.

pico hydro generator. ACREST has hired a technician from Kenya for the design and fabrication of 500 W pico hydro generators for the electrification of households. Fig. 7 shows the assembly of a pico hydro generator.

The centre is involved in the construction of a micro hydro scheme with a generation target of 100 kW. However, there are problems in the project realisation due to the trial by error method that has been adopted for sizing of the penstock diameter. Initial tests have resulted in voltages in the kV range and high frequencies instead of the rated output voltage of 380 V at 50 Hz. The penstock under construction to the generator house is shown in Fig. 8.

4. Identification of stakeholders for sustainable renewable energy applications

The four case studies presented in this paper show that all of the renewable energy applications were initiated by indigenes that live outside the beneficiary communities. Funds for two projects were provided by two indigenes, one project had funding from abroad through the initiative of an indigene and the fourth project benefited 70% funding from a development partner. Projects realized at two sites (Baleng Djetcha and Ndoh-Djuttisa) were mainly for the social integration of rural communities. However, the notion of free energy and the lack of responsibility in the beneficiary communities for installed energy systems were the main contributors for inoperative or failed systems. Revenue collection on a fee-for-service basis over 14 months of operation could have constituted the initial funds for the importation of another inverter. Other problems identified include project design, implementation and post-installation supervision that do not involve research laboratories in Cameroon. This situation is partly due to the limited number of researchers in the area of renewable energy in Cameroon and the lack of laboratory equipment for the promotion of research and training of technicians and engineers.

Other problems include the importation of renewable energy equipment that cannot be maintained locally due to lack of qualified technicians and engineers. There are very few renewable energy enterprises that can conduct site surveys, size, install and commission renewable energy systems. There are also a limited number of qualified technicians and engineers for system operation and maintenance. The inability of villages to formulate socially oriented projects reduces changes of access to funds provided by development partners. Thus, there is the need for microfinance institutions to issue loans to financially viable and organised groups, associations or villages for the acquisition, installation and commissioning of renewable energy systems in Cameroon.

Loans and terms of payment shall depend on energy delivery model and the established capacity to pay of households. In literature, the financial and economic viability of some renewable energy options has been conducted for households, businesses or a village [21–26]. A financial analysis of six case studies involving a switch to solar home systems (SHS) by households and businesses in Bangladesh found a payback period of 2–3 years for SHS used in income generating activities [22]. The findings from the studies conducted in Bangladesh suggested that monthly installments should be equivalent to the monthly energy expenditure of the customer. It is therefore necessary to conduct socio-economic studies in non-electrified villages of Cameroon for the determination of monthly energy expenditure of households on traditional and modern forms of energy. This will facilitate the evaluation of financial and economically viable renewable energy options.

In one case a NGO promoter of renewable energy technologies conceived the pico-hydro project, obtained funding, and coordinated the realisation of the project. The NGO also resolved problems in the management committee that stopped the normal operation of the pico hydro scheme. Consequently, NGOs with social orientated objectives are identified as structures that will continue to play a vital role for groups or communities that lack income generating activities that can enable them secure loans from microfinance institutions.

The successful implementation of renewable energy projects is currently based on foreign expertise. Considering that there are more than 30,000 villages in Cameroon without electricity [2], it is extremely important that Cameroonian universities start training a lot of technicians and engineers that will be needed by NGOs operating in various parts of the country. This necessitates the formulation of university programs on renewable energy technologies that would provide graduates the competence for the sizing, installation, supervision and post-installation maintenance. The creation of the Department of Renewable Energy at the Institut Supérieur de Sahel of the University of Maroua by the Cameroon government in 2008 is a step towards this direction. Considering that there are more than 30,000 non-electrified villages in Cameroon and the need to develop regional models for sustainable electrification of remote villages, more departments should be created in other state universities.

The significant number of technicians and engineers that will be trained by state universities will have the required competence

to work in renewable energy enterprises that have been identified as the structures that would size, and install renewable energy systems. The installation of remote monitoring systems by Universities would facilitate the rehabilitation of inoperative systems or serve as a basis for student projects. The data remotely acquired would also be a useful didactic material for training programs on renewable energy technologies. A web-based learning facility has been implemented in Australia [20].

5. Conclusion

Insufficient energy generation and poor coverage of the nation by existing independent grids have lead to low national access rate of 11%. The current costs for low voltage connections are unaffordable to urban and rural households that lack income generating activities. The monthly expenditure on low electricity consumptions of 5.8–25 kWh are 1.46–2.92 €. Such low energy applications can be met with renewable energy options. Some renewable energy applications that have been realised with various sources of funding have been presented in this paper.

The lessons learnt from the current state of these applications guided the identification of the roles of the stakeholders for sustainable renewable energy applications. This study revealed that local management committees must be in charge of the supervision, operation and maintenance of installed energy systems as well the collection of revenue on a fee-for-service basis. Microfinance institutions were identified as the structures that could award loans to organised groups or communities based on the established monthly energy expenditures. NGOs' promoters of renewable energy technologies were identified as the structures that could provide technical assistance for the conception of projects, the procurement of funding from cooperation partners and for the realisation of projects. Renewable energy enterprises were identified as structures that would be competent for the sizing, installation and post-installation maintenance of renewable energy equipment that is currently being imported.

References

[1] Nfah EM, Ngundam JM. Feasibility of pico-hydro and photovoltaic hybrid power systems for remote villages in Cameroon. Renewable Energy 2009;34(6):1445–50.

[2] Nfah EM. Design of a low voltage mini-grid based on renewable Energy Plants: Load Management and Generation Scheduling. PhD Thesis, Cameroon: University of Yaoundé I, ; 2007.

[3] Mbaka NE, Mucho NJ, Godpromesse K. Economic evaluation of small-scale photovoltaic hybrid systems for mini-grid applications in Far North Cameroon. Renewable Energy 2010;35(10):2391–8.

[4] Nfah EM, Ngundam JM, Tchinda R. Modelling of solar/diesel/battery hybrid power systems for Far North Cameroon. Renewable Energy 2007;32(4):832–44.

[5] Rana S, Chandra R, Singh SP, Sodha MS. Optimal mix of renewable energy resources to meet the electrical energy demand in villages of Madhya Pradesh. Energy Conversion and Management 1998;39(3-4):203–16.

[6] Valente LCG, Anibal de Almeida SC. Economic analysis of diesel/photovoltaic hybrid system for decentralised power generation in Northern Brazil. Energy 1998;23(4):317–23.

[7] Katti PK, Khedkar MK. Alternative energy facilities based on site matching and generation unit sizing for remote area power supply. Renewable Energy 2007;32(8):1346–62.

[8] Nipon K. Photovoltaic hybrid systems for rural electrification in the Mekong countries. PhD thesis. Germany: University of Kassel; 2005.

[9] Zaida C. Modèle d'électrification rurale pour localités de moins de 500 habitants au Sénégal. Juillet 2005–Janvier 2006. 〈http://www.peracod.sn〉.

[10] Somashekhar HI, Dasppa S, Ravindranat NH. Rural bioenergy centres based on biomass gasifiers for decentralised power generation: case study of two villages in southern India. Energy for Sustainable Development 2000;4(3):55–63.

[11] Youm I, Sarr J, Sall M, Kane MM. Renewable energy activities in Senegal: a review. Renewable and Sustainable Energy Reviews 2000;4(1):75–89.

[12] Koita Z, Dahouenon AM. Diaoulé and Ndiébel photovoltaic plants: 6 years operating experience. In: Proceedings of the ISES solar world congress.

[13] Dung TQ, Anisuzzaman M, Kumar S. Demonstration of muti-purpose battery charging station for rural electrification. Renewable Energy 2003;28:2367–78.

[14] Gustavsson M, Ellegard A. The impact of solar home systems on rural households. Experiences from Nyimba Energy Services Company in Zambia. Renewable Energy 2004;29:1059–72.

[15] Gustavsson M. With time comes increased loads: an analysis of solar home systems use in Lundazi, Zambia. Renewable Energy 2007;32:796–813.

[16] Morante F, Zilles R. A field survey of energy consumption in solar home systems. Energy for Sustainable Development 2007;11(1):68–77.

[17] Ketlogetswe C, Mothudi TH. Solar home systems in Botswana—opportunities and onstraints. Renewable and Sustainable Energy Reviews 2009;13:1675–8.

[18] Burger B, Cramer G, Kleinkauf W, Zacharias P. Battery inverter for modularly structured PV power supply systems. In: Proceedings of the PV hybrid power systems conference.

[19] Talla HS, Fotso GGC. Etude d'un système éolien de pompage d'eau: Cas de l'éolienne de Ndoh-Djuttitsa. Projet de fin d'études en Licence. Département de Génie Electrique. IUT Fotso Victor de Bandjoun. Cameroun: Université de Dschang; 2006. 74p.

[20] Lund CP, Wilmot N, Pryor T, Cole G. Demonstrating remote area power supply systems on the World Wide Web. Renewable Energy 2001;22:345–51.

[21] Chaurey A, Kandpal TC. A techno-economic comparison of rural electrification based solar home systems and PV micro-grids. Energy Policy 2010;38:3118–29.

[22] Mondal MAH. Economic viability of solar home systems: case study of Bangladesh. Renewable Energy 2010;35:1125–9.

[23] Chaurey A, Kandpal TC. Solar lanterns for domestic lighting in India: viability of central charging station model. Energy Policy 2009;37:4910–8.

[24] Gullberg M, Ilskog E, Katyega M, Kjellstrom B. Village electrification technologies—an evaluation of photovoltaic cells and compact fluorescent lamps and their applicability in rural villages based on a Tanzanian case study. Energy Policy 2005;33:1287–98.

[25] Kaldellis JK, Zafirakis D, Kondili E. Energy pay-back period analysis of stand-alone photovoltaic systems. Renewable Energy 2010;35:1444–54.

[26] Singh PP, Singh S. Realistic generation cost of solar photovoltaic electricity. Renewable Energy 2010;35:563–9.